# Ice Physics - Part 2

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# Plan

1. Sea Ice Drift
2. Ridging
3. Sea Ice and Climate
4. Video Presentation

References:

a) *Ice in the Ocean* by Peter Wadhams (2000)

b) *Arctic and Antarctic Sea Ice, 1978-1987* by Gloersen et al. (1992) (AKA the blue SSMR ice atlas)

c) Most slides in Sea Ice and Climate section are from Don Perovich of Cold Regions Research an engineering Lab (CRREL).

d) The video is by Tom Grenfell (U. Washington) and collaborators from CRREL and Seelye Martin (U. Washington).

# Sea Ice Drift

**Ice Drift** is governed by the balance of forces acting on the ice (Newton's Third Law of motion), which is

$$\boxed{\text{Mass X Acceleration}} = \boxed{\text{Air stress}} + \boxed{\text{Water stress}} + \boxed{\text{Coriolis Force}}$$
$$+ \boxed{\text{Internal Ice Stress}} + \boxed{\text{Sea Surface Tilt term}}$$

**Air stress** and **water stress** are frictional drag from the air and water, respectively.

The **Coriolis Force** is proportional to the speed and weight of the object. In the Northern Hemisphere it is 90 degrees to the right of the direction of motion; in the Southern Hemisphere it is 90 degrees to the left.

**Internal Ice Stress** is the result of ice interacting (colliding, rubbing, ridging, rafting, etc.) with other ice or the coast. This term becomes significant only in ice concentrations greater than about 85% and when ice is thicker.

**Sea Surface Tilt** is the "piling up" of water against the shore by the mean wind stresses. Ice will tend to slide down the sloping water surface. This term is small and can be ignored for all practical purposes.

# Sea Ice Drift

**“Free” Ice Drift** ignores the effect of internal ice stress and sea surface tilt.  It is the balance of air stress, water stress and the Coriolis force.  As shown below, it is fairly easy to compute the free drift of sea ice ... if you know the wind.

Computing the effect of internal ice stresses is a very complicated and computationally demanding problem.  This is a major challenge for climate models and for numerical forecasting models like PIPS.

# Sea Ice Drift

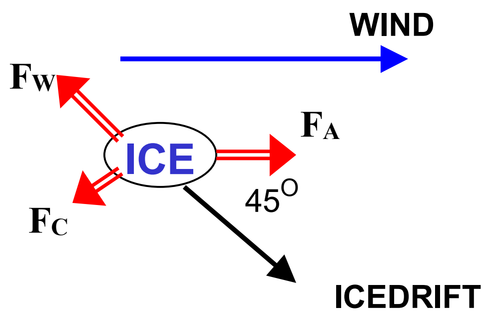
**Symbols:**

$F_A$ - air stress

$F_W$ - water stress

$F_C$ - Coriolis force

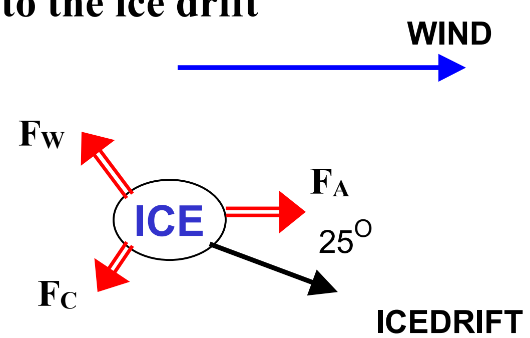
**Assume that the water is still:**




**TOP VIEW**

**The water stress is in the opposite direction of the drift direction. This resulting drift is about 45 degrees to the right of the air stress.**

**Now let water move in response to the ice drift (more accurate assumption):**




**TOP VIEW**

**The water stress is against the direction but slightly to the left of the drift direction. This results in the drift being only about 25 degrees to the right of the air stress.**

# Sea Ice Drift

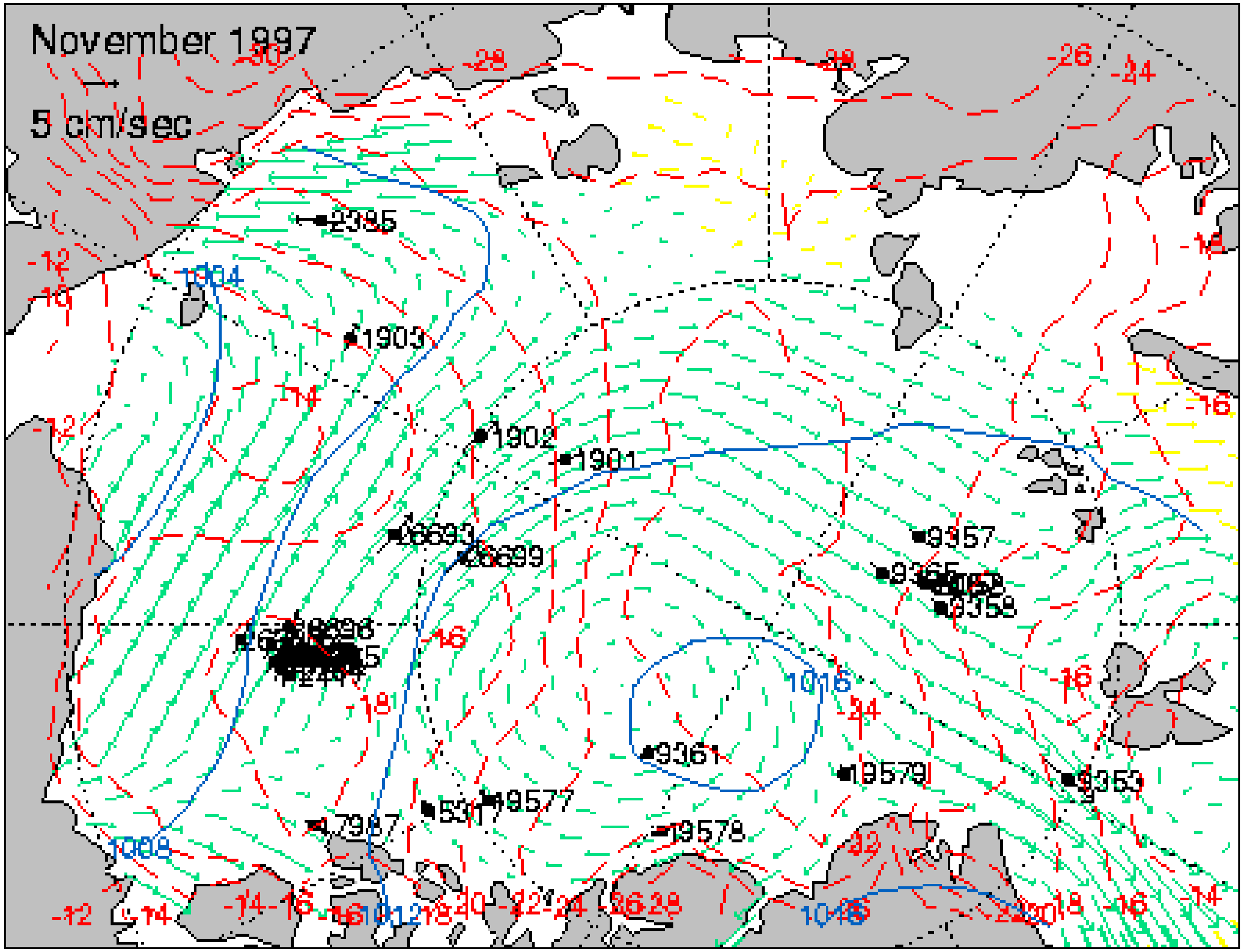
## **Free Drift** and the **surface pressure pattern**.

Recall that the near surface wind is about 25$^{O}$ to the left of the surface geostrophic wind. Since free ice drift is about 25$^{O}$ to the right of the surface wind stress, **ice drift should be approximately parallel to surface isobars** (or the 1000-mb pressure level height).

**From IABP**

Green arrows are drift interpolated from buoy motions.

Blue line is men surface pressure.

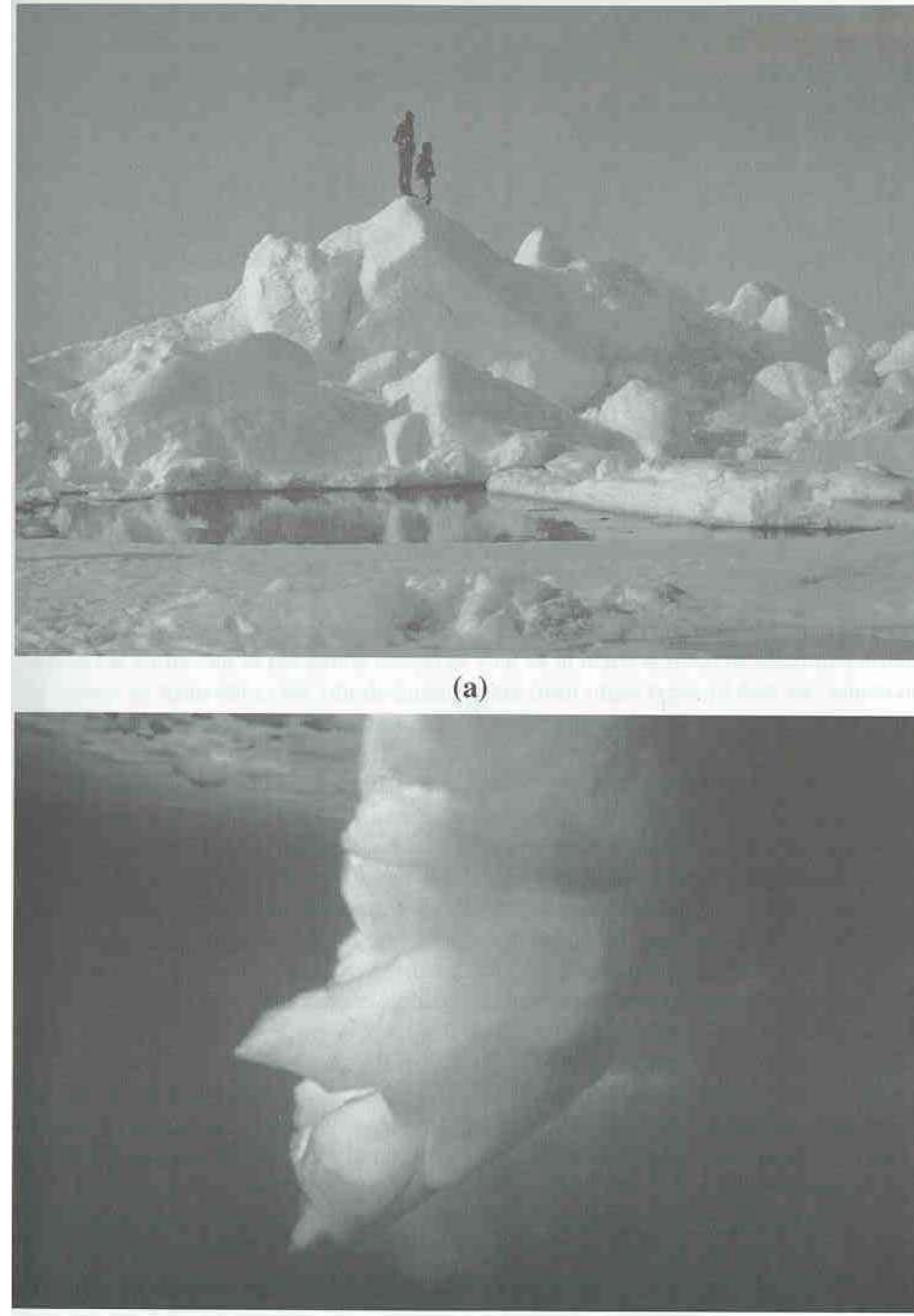


# Ridging

When sea ice does not drift freely …

it undergoes **deformation** such as **ridging** and **rafting**.

Examples of sails and keels, from Wadhams (2000).



(a)

(b)

**Figure 2.20.** (a) The sail and (b) the keel of an Arctic pressure ridge.

# Ridging

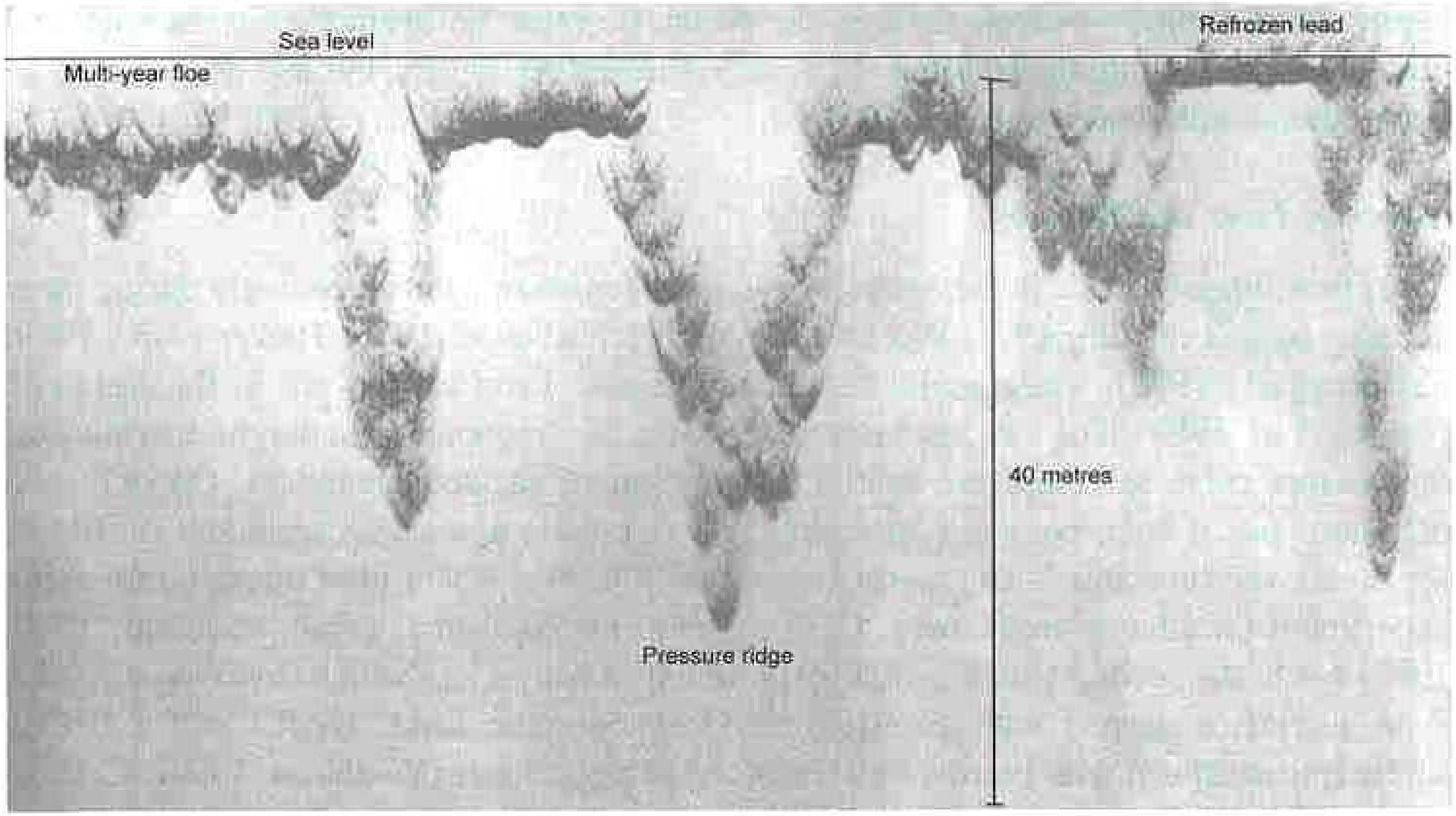



**Figure 5.11.** An under-ice sonar profile obtained by a submarine in the Arctic Ocean.

Sonar profile of ridged sea ice in the Arctic Ocean, from Wadhams (2000). Horizontal dimension appears compressed.

# Polynyas

**Definition:** An area of water poleward of the ice limit that remains open for all or part of the winter. Polynyas persist longer than leads and are not maintained by atmospheric heating.

A **sensible heat** polynya is formed when a continuous source of heat from the ocean prevents ice from forming.

A **latent heat** polynya is formed by the continual removal of ice from a open-water patch by wind or ocean currents. Typically, they occur near a fixed feature such as land or fast ice.

Many polynyas appear to have both latent and sensible heat mechanisms at work.

For more information see pp. 73-79, 127-133 of Wadhams (2000).

# Polynyas

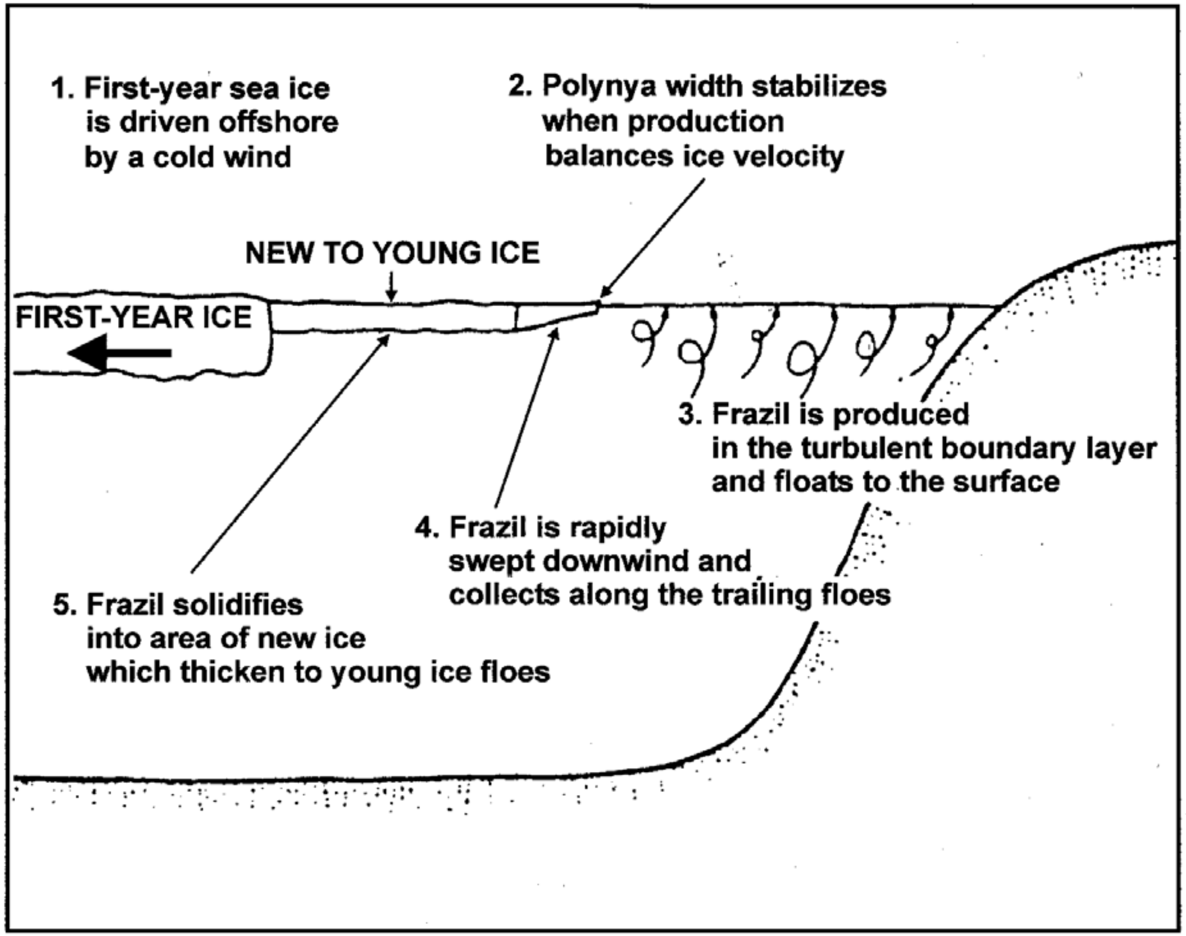



**Figure 4.8.** Simple dynamics of a wind-driven coastal polynya (after Pease, 1987).

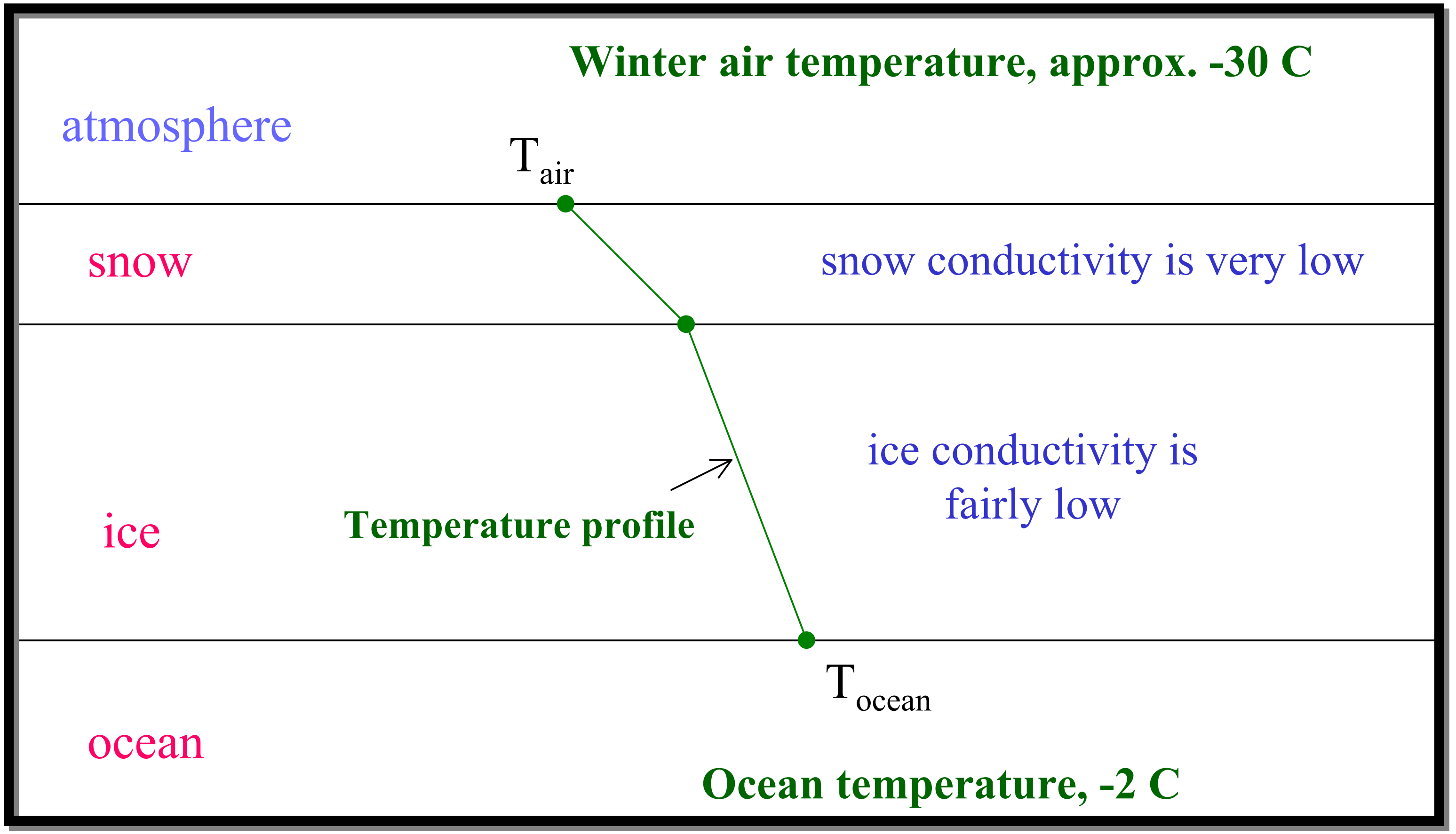
Conceptual model of coastal (latent heat) polynya based on research of polynyas at St. Lawrence Island, Bering Sea, by Carol Pease. Figure from Wadhams (2000).

# Sea Ice and Climate

a. Impact of sea ice on climate
b. Impact of climate on sea ice
c. The ice-albedo feedback
d. Observed changes in Arctic sea ice

# a) The Impact of Sea Ice on Climate

**Sea Ice is a Thermal Insulator in Winter.**
Energy loss from the ocean to the atmosphere would be much greater if sea ice and snow did not insulate it from the cold atmosphere.



# a) The Impact of Sea Ice on Climate

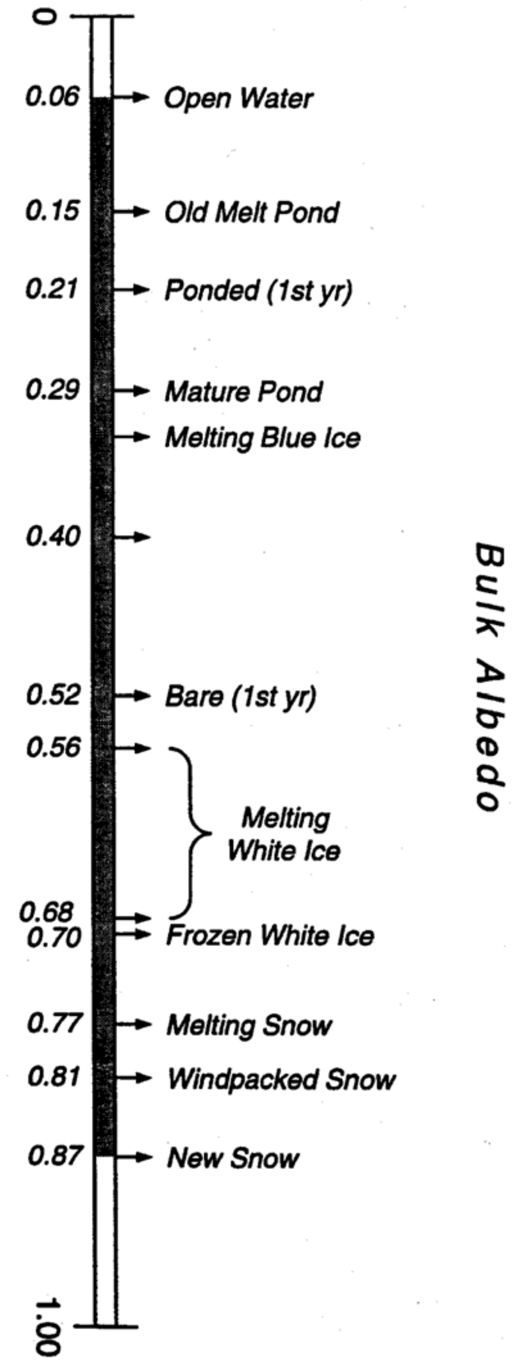
**Sea Ice is a Solar Reflector.**

The albedo (reflectivity) of sea ice and snowis much greater than that of the ocean.

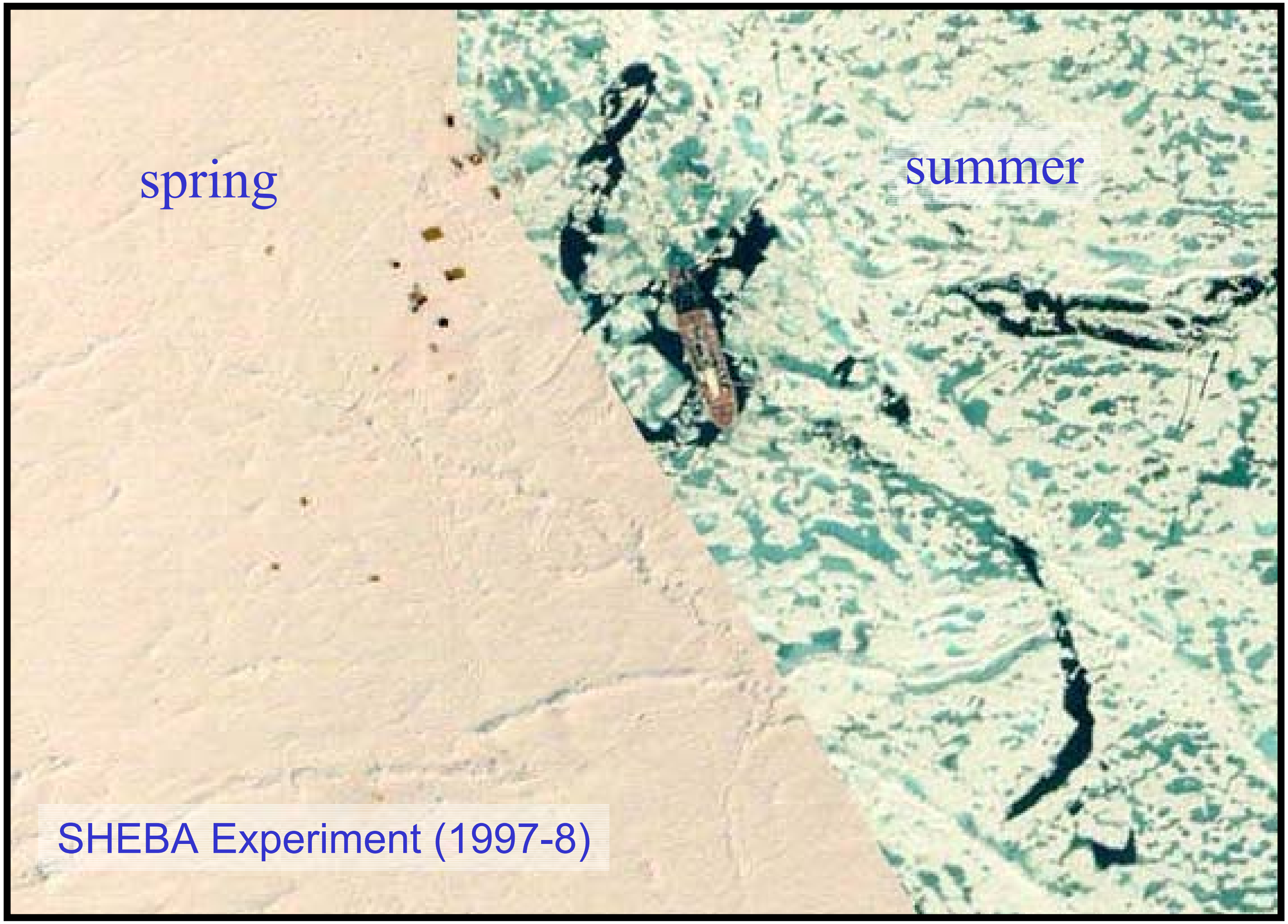
The presence of sea ice and snow drastically reduces the amount of sunlight absorbed, making the world a little bit cooler.

Figure from Wadhams (2000).

$$\boxed{Albedo = \frac{reflected}{incident}}$$



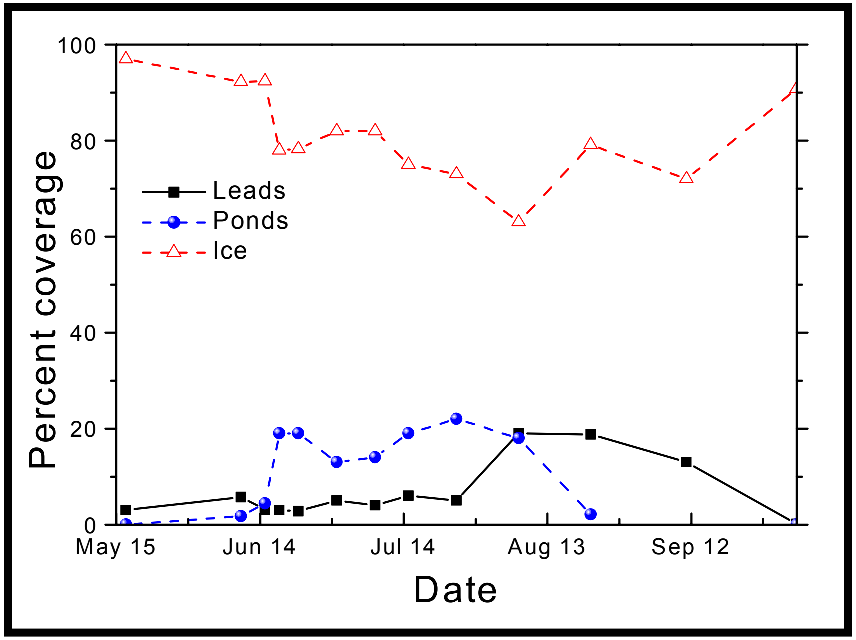
## a) The Impact of Sea Ice on Climate

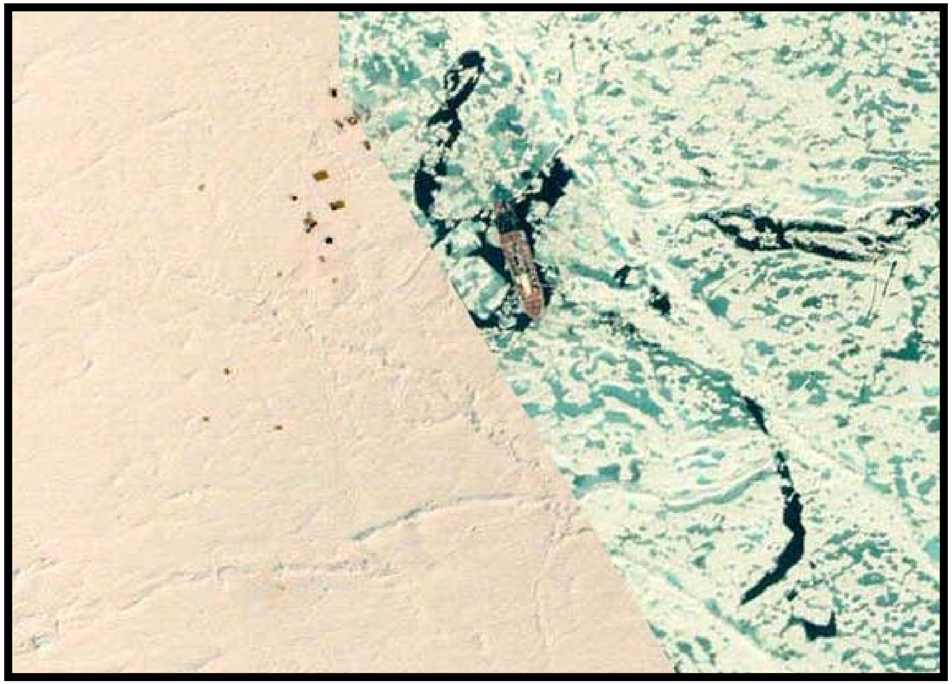


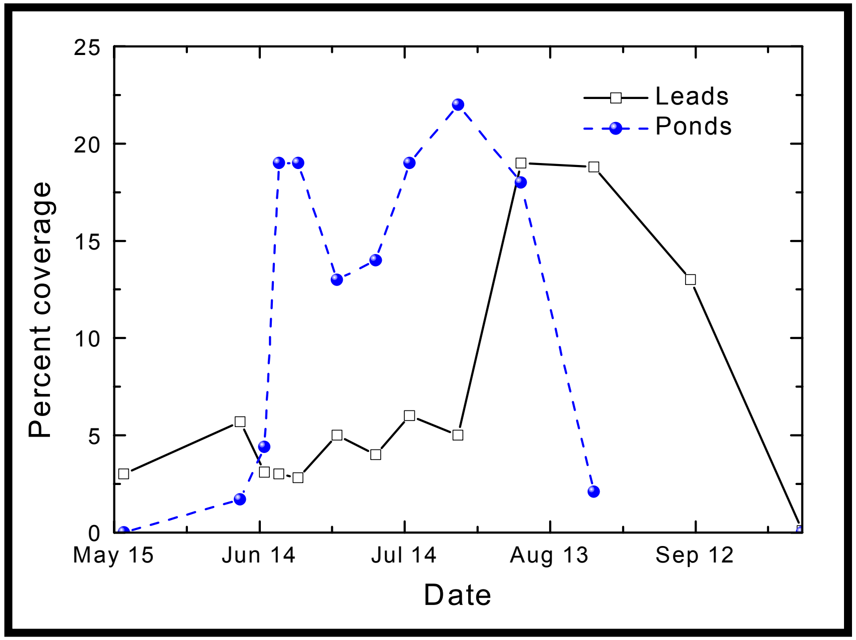

This picture (provided by Don Perovich of CRREL) is an aerial view of the SHEBA ice camp in spring and summer of 1998. The ice is covered by snow in spring and has dark leads and blue melt ponds in summer. Notice the difference in reflectivity!

# “Scaling up”: Aerial areal surveys

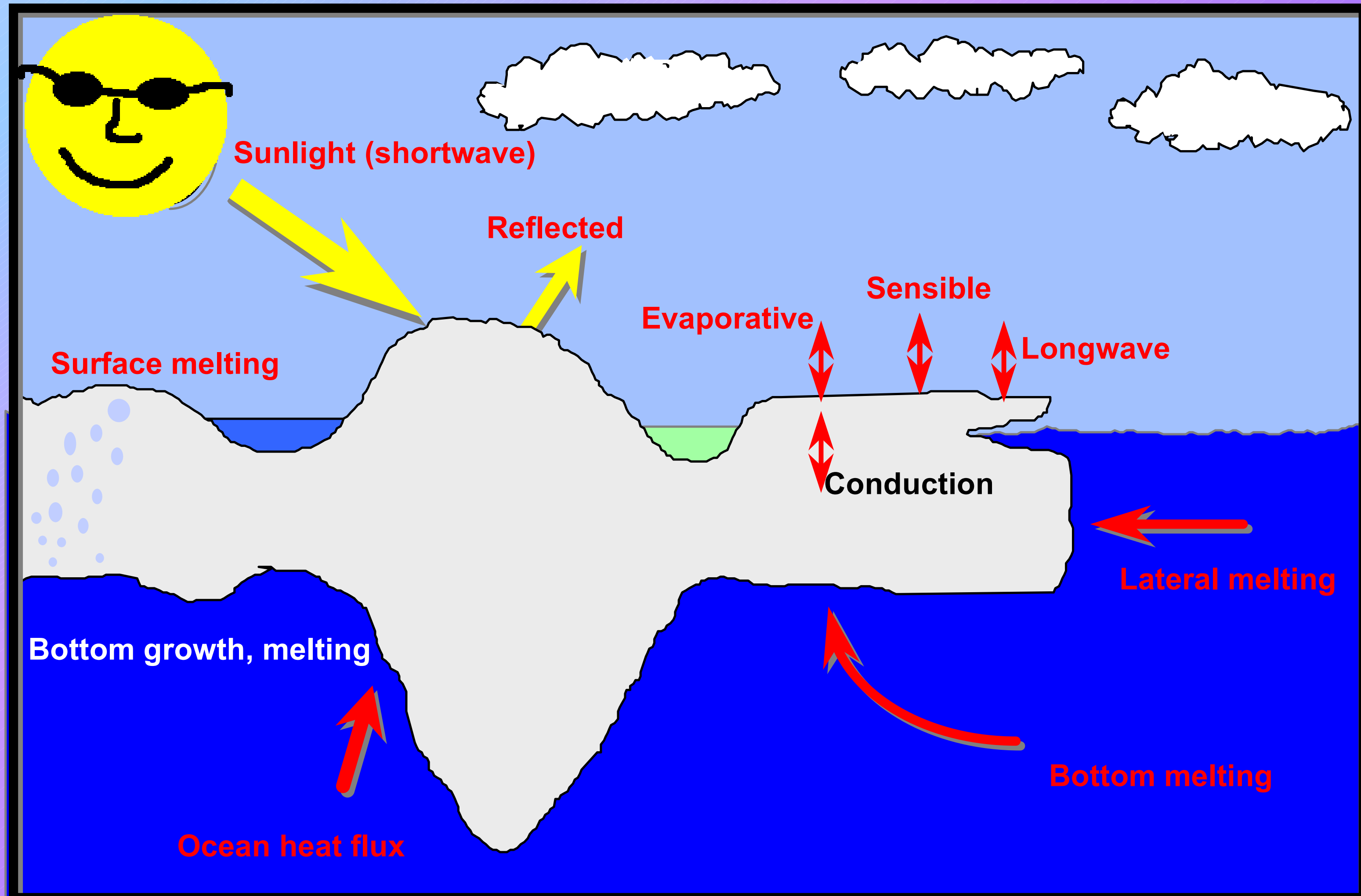
- Results from helo flights and NRO image
- Each point more than 100 km$^2$
- 3-5% leads for most of summer
- Big jump after divergence event
- Pond area increases rapidly,
- Then decreases rapidly
- Gradually increases until freezeup



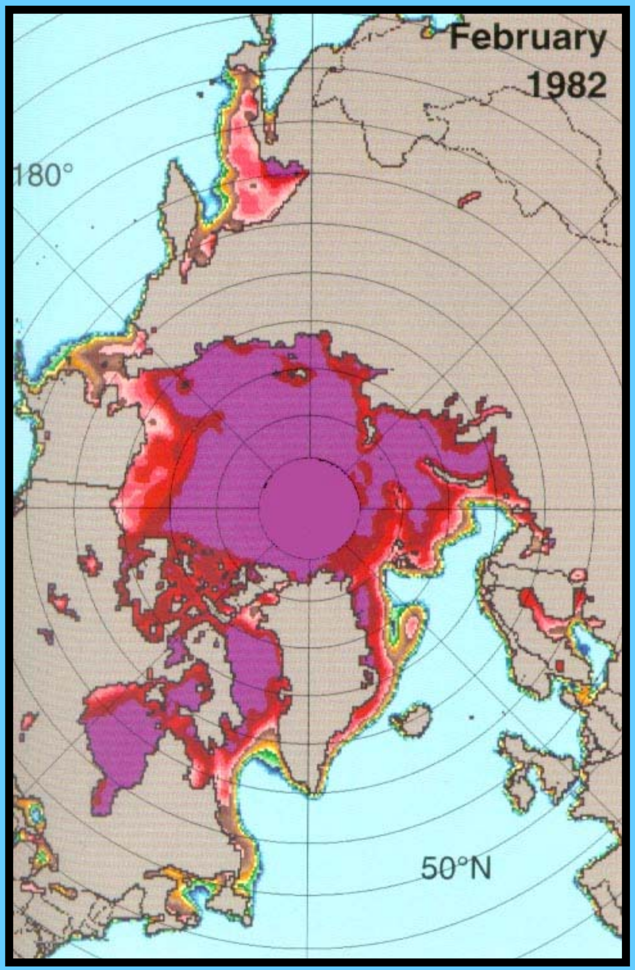


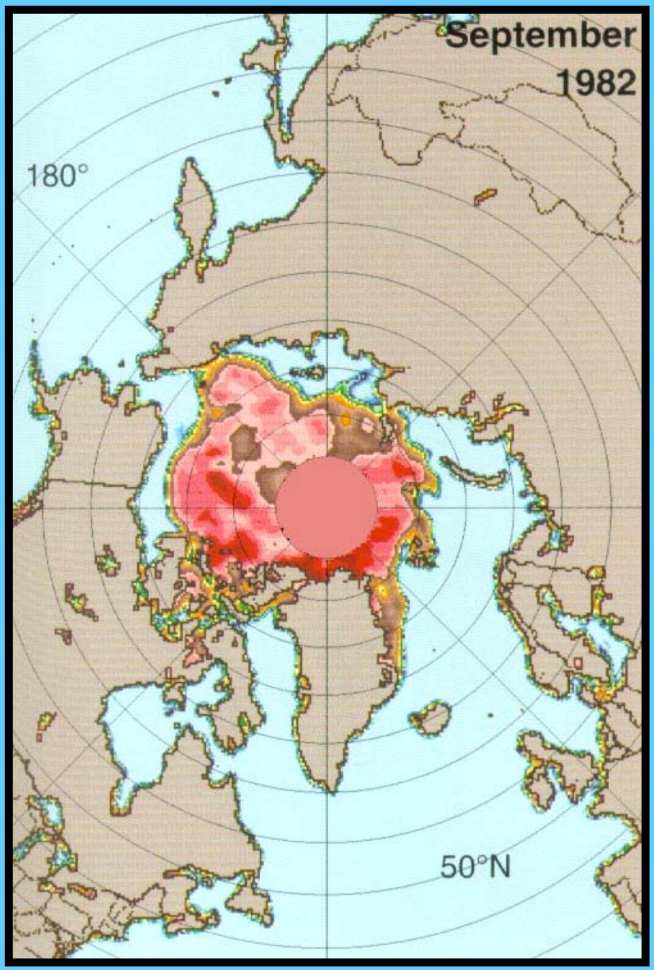
# b) The impact of climate on sea ice: the surface heat budget

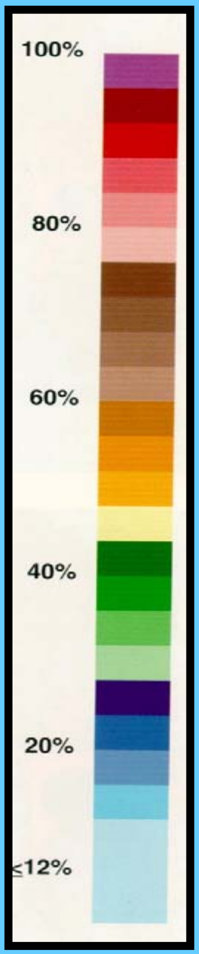



**Net shortwave + net longwave + sensible + evaporative + conduction = melt / freeze**

# b) The impact of climate on sea ice:
# The Mean Global Distribution of Sea Ice



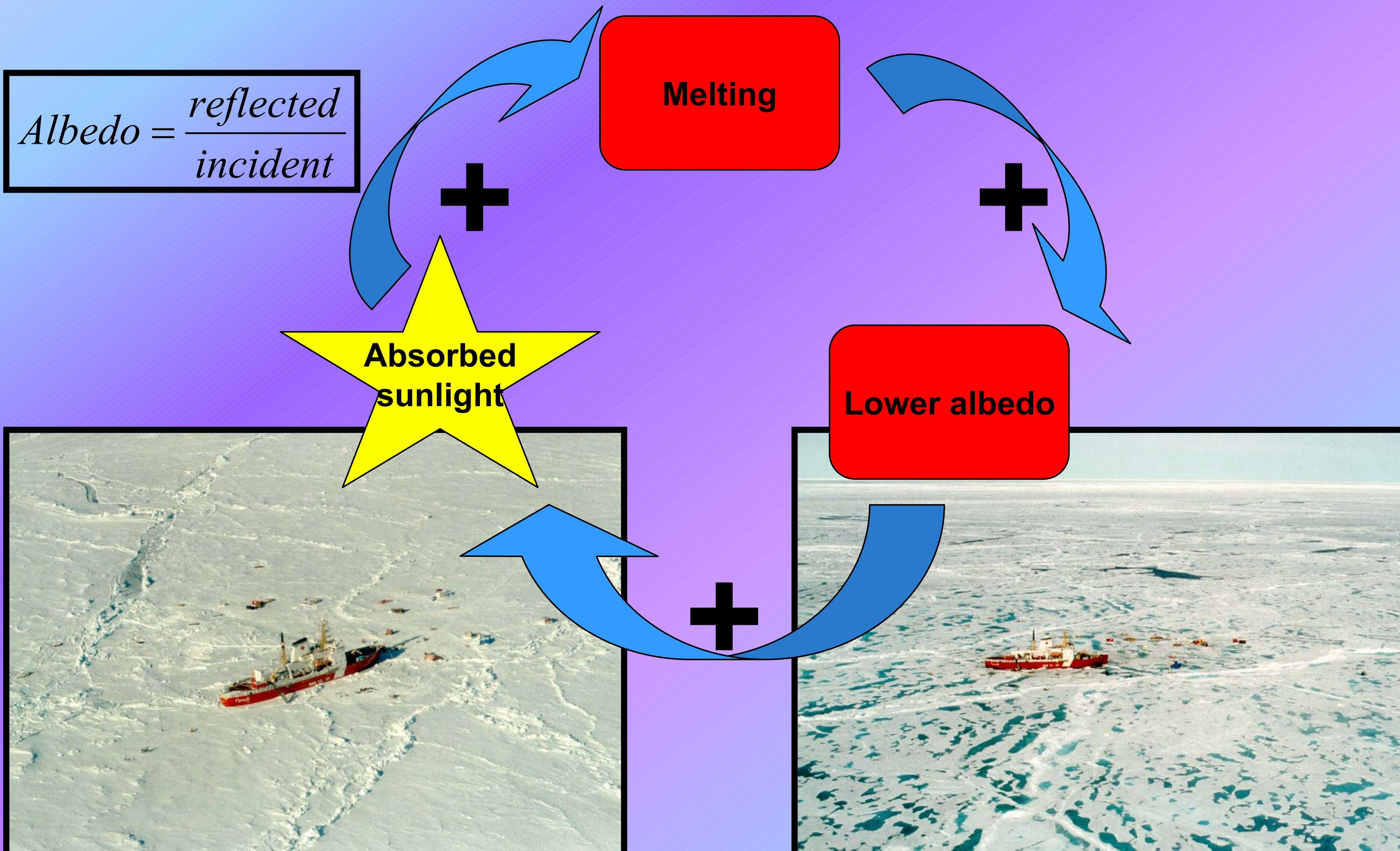




**Key Factors:**

1) Average incoming sunlight (why ice is at poles, not tropics)
2) Oceanic currents (why winter ice extent is 75-80 N in East)
3) Weather patterns

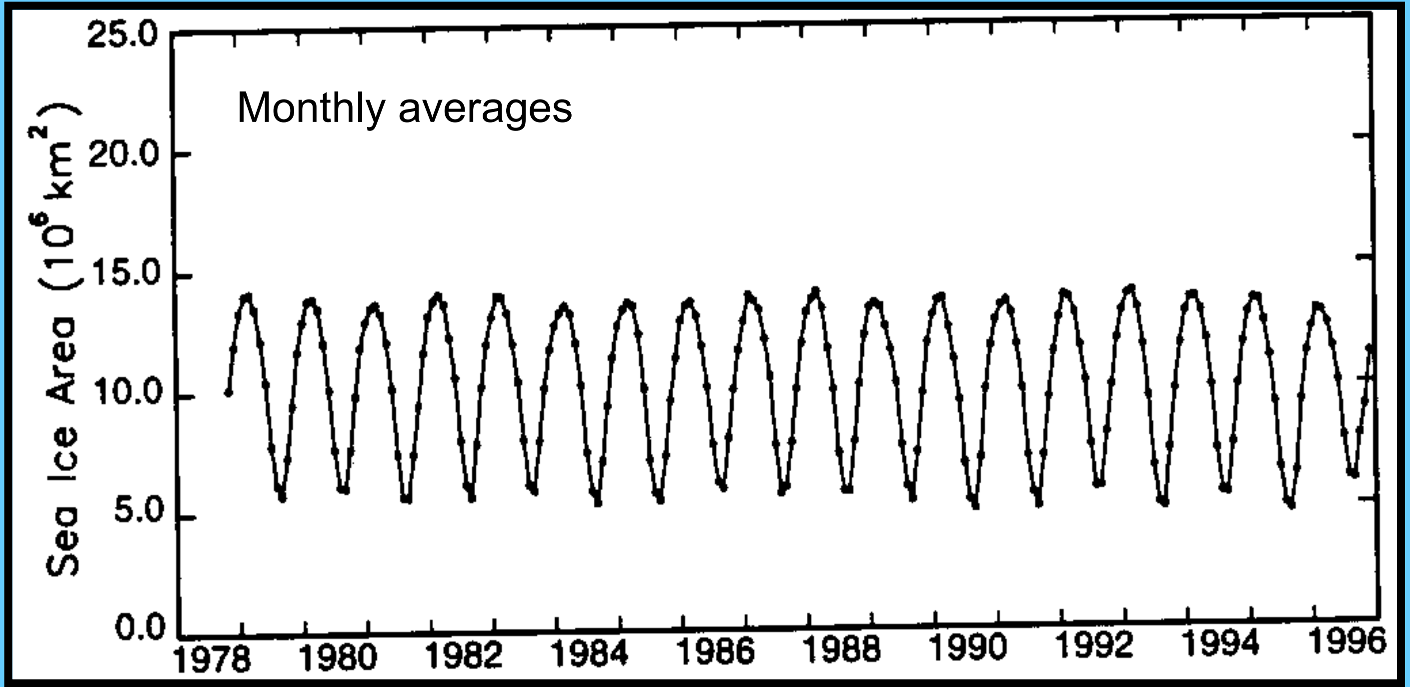
# c) The Role of Sea Ice in Climate Change
# The Ice-Albedo Feedback increases sensitivity

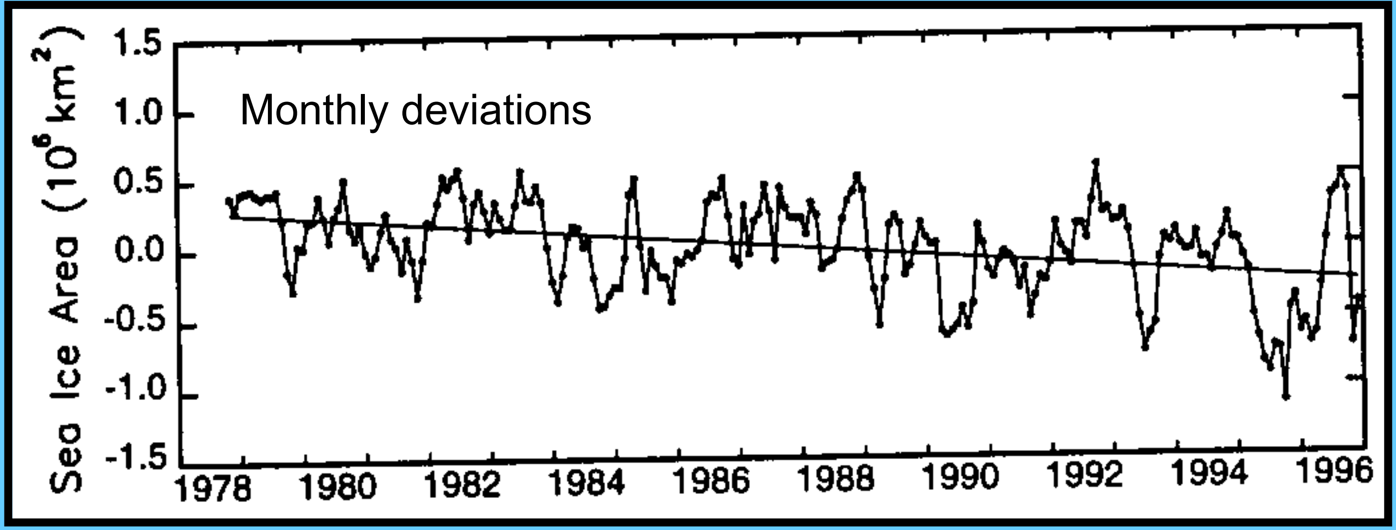
$$Albedo = \frac{reflected}{incident}$$



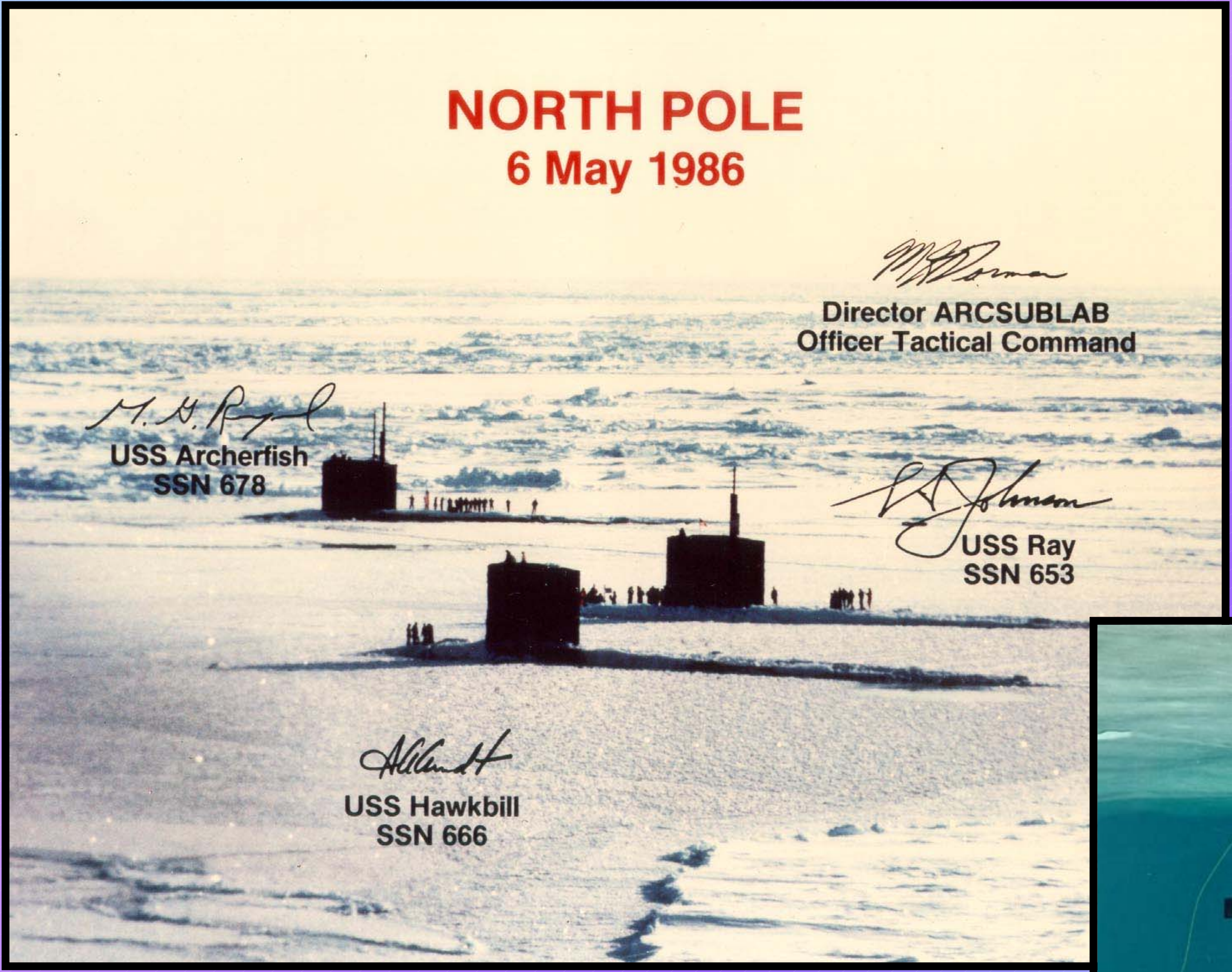
# d) Sea Ice Changes: Ice Extent from Satellite

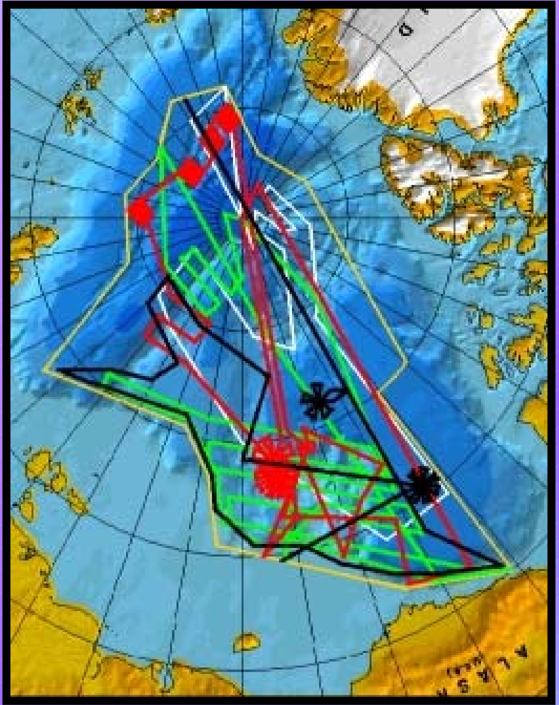
- Large seasonal dependence
- Some interannual variability
- Downward trend in ice extent
- ~ 3 % per decade
- Large regional variability (much less in Barents; slightly more in Baffin Bay)

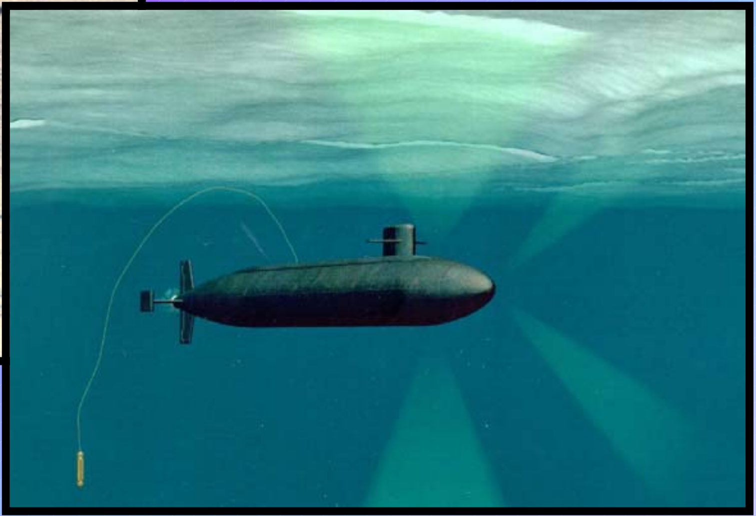


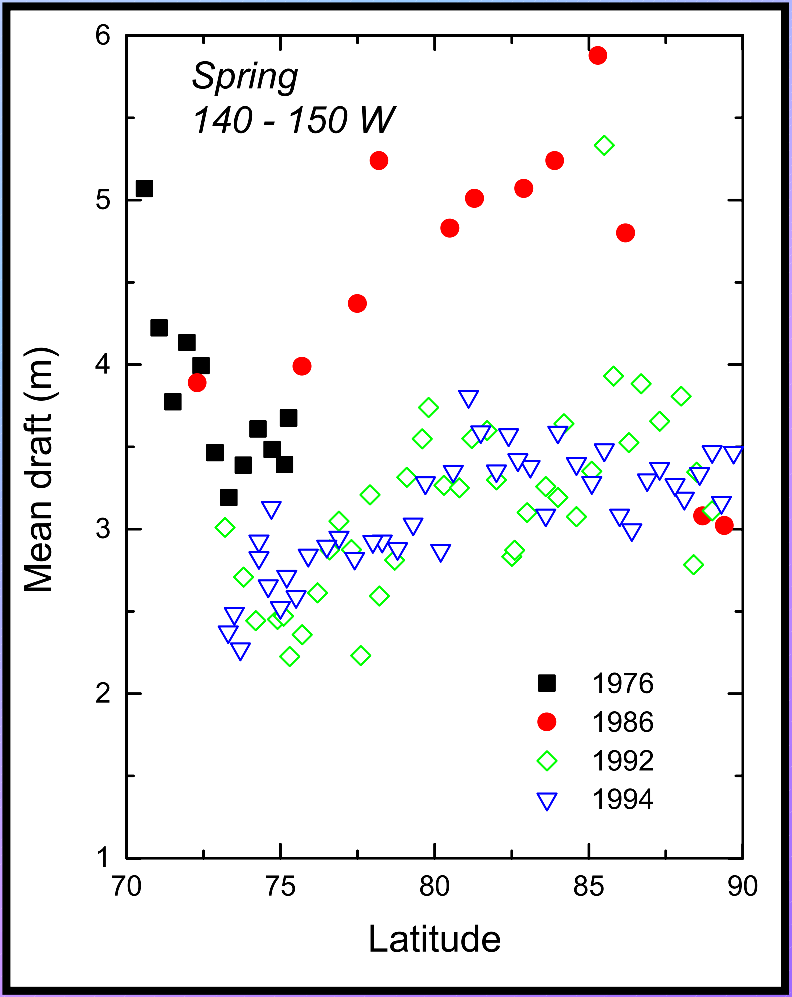
# d) Sea Ice Changes: Submarine Surveys of Ice Thickness



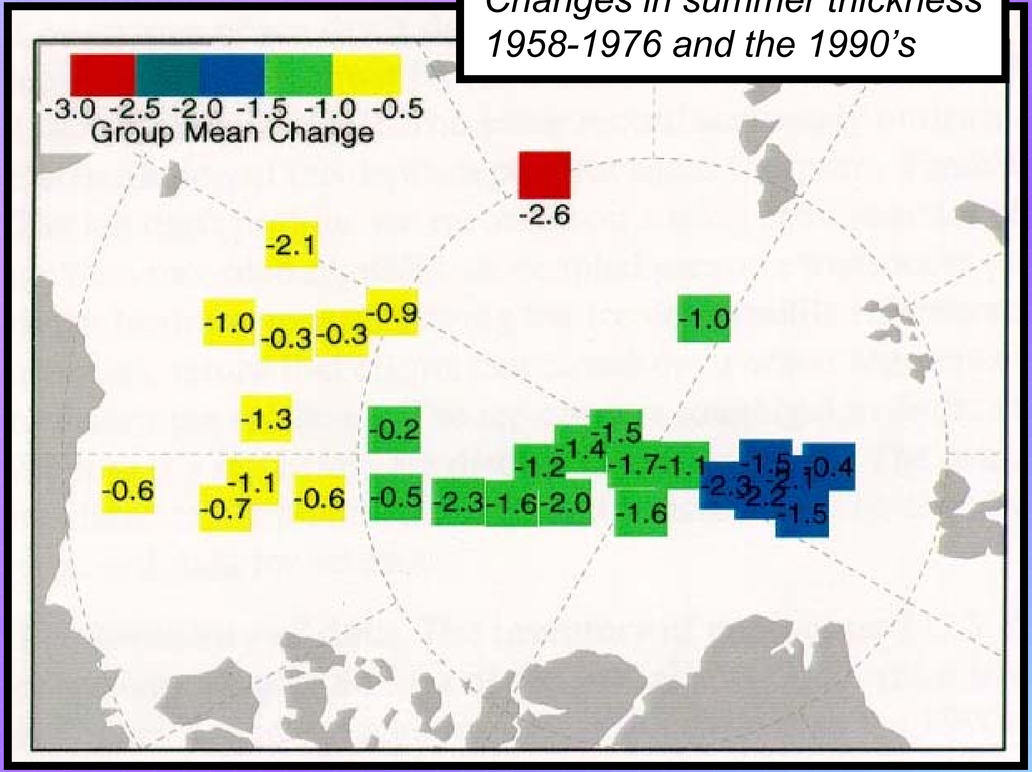


# Changes in ice thickness




Tucker, pers. comm.

Changes in summer thickness
1958-1976 and the 1990's




Rothrock et al., GRL

- Sparse dataset in space and time
- Significant spatial variability
- Considerable interannual variability
- Difficult to separate trends from variability

# Video

**Part 1:**

- Frazil then grease ice and pancake ice are formed in an outdoor man-made pond at Cold Regions Research and Engineering Lab in New Hampshire.
- Waves are produced by a wave machine but the cooling is natural. The purpose of the experiment is to determine how radiative sensors react to the transforming ice.
- The experiment begins at around 9 PM on January 20, 1990 and finished the next afternoon. The picture quality is not very good during the night.
- Provided by Tom Grenfell of U. of Washington (tcg@atmos.washington.edu).

**Part 2:**

- Aerial motion pictures of wave propagating through grease ice off of Alaska.
- The second part shows waves propagating through grease ice in an laboratory wave tank.
- Experiment performed by Seelye Martin of U. of Washington.

# Ice albedo feedback

$$Albedo = \frac{reflected}{incident}$$